Fostering Green Economy in New Jersey under the aegis of Regional Greenhouse Gas Initiative

Dileep K. Birur[1], Pankaj Lal[2], Todd Levin[3*], Zhi Zhou[3*], Bernabas Wolde[2], Taylor Wieczerak[4], and Prakash Thimmapuram[5*]

[1] *Academic Affiliate, College of Science & Mathematics, Montclair State University, NJ, USA. Email:* dbirur@gmail.com

[2] *Clean Energy & Sustainability Analytics Center, Montclair State University, Montclair, NJ, USA.*

[3] *Argonne National Laboratory, Lemont, IL, USA.*

[4] *New Jersey Department of Environmental Protection, Trenton, NJ, USA.*

Authors' Disclosure Statement: No competing financial interests exist.

*The Argonne National Laboratory team contribution was limited to the technical power system modelling analysis outlined in the abstract/paper.

Abstract submitted for presentation at the 25th Annual Conference on Global Economic Analysis "Accelerating Economic Transformation, Diversification and Job Creation."

Kigali, Rwanda, June 8-12, 2022.

Acknowledgements:

Support for this work was provided by the New Jersey Board of Public Utilities (NJBPU).

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Abstract

The state of New Jersey (NJ) re-joined Regional Greenhouse Gas Initiative (RGGI) in January 2020, the first mandatory market-based program in the US to reduce greenhouse gas (GHG) emissions. For RGGI's continued success, it must address the issue of leakage, a situation that results when an action taken to reduce GHG emissions in one area causes an increase in emissions in another area where the rules that govern emissions are not as strict. We analyze the economywide impact of New Jersey's rejoining RGGI, by developing and uniquely integrating two models – a power system investment and dispatch model, and an economy-wide computable general equilibrium (CGE) model. We analyzed the emission leakage impacts of six different scenarios varying with respect to the sensitivity of some key parameters, such as: Mid CO_2 Price (Reference), Low CO_2 Price, High CO_2 Price, High Natural Gas Price, High PJM market Demand, and Low Natural Gas Price in New Jersey. For each scenario, we modeled power system operations from 2020 through 2030 for a Reference scenario wherein NJ does not join RGGI and a policy sensitivity scenario in which it does. The results revealed, participation in RGGI results in New Jersey based power producers reducing their CO_2 emissions by 45% (8.7 million tons [mt]) between 2020 and 2030. However, the model results also show that emissions from units located outside of New Jersey will increase by 11.6 mt, more than offsetting the reductions realized within New Jersey. Cumulatively, the CGE model predicted an increase in real gross state product (GSP) across all the scenarios when New Jersey joined RGGI. The GSP change was found be the highest in the High CO_2 Price scenario (0.82%) and lowest in the Low CO_2 Price scenario (0.56%). The model predicted cumulative change in employment across sectors in the Reference scenario, with wind power generation gaining the highest number of jobs by 2030, followed by solar power, and transportation sectors. Overall job loss across other sectors of the economy is relatively small. As implied from these results, New Jersey reduces CO_2 emissions significantly and boosts its renewable electricity portfolio considerably in the coming decade, thereby positively contributing to the growth of the greener economy.

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1. Introduction

New Jersey has been at the forefront of greening its economy by establishing an emission target of 80% by 2050 and 50% by 2030, below their 2006 greenhouse gas (GHGs) emission levels. Towards this goal, one of the state's most visible efforts lies in a significant push to increase renewable energy options, both to bolster generation and to cut down on GHGs emissions. Renewable energy has rapidly evolved over the past few decades, and has risen to prominence due to falling costs of installation and maintenance, as well as increased efficiency. While New Jersey's strategy to move towards a clean energy future is a significant step towards reducing GHGs and mitigating climate change effects, the unfortunate truth is that such efforts, while critical, occur over a fairly long term, and are largely unable to affect GHG emissions on shorter time scales. Thus, it is imperative that emissions are controlled during this transition and beyond, particularly in power plants where significant amounts of CO_2 are generated daily to provide energy. Furthermore, these efforts suffer from a loss of effectiveness if the efforts are only considered in New Jersey, as local effects can only mitigate global climate change phenomena so much.

To confront these problems, New Jersey made the decision to once again join Regional Greenhouse Gas Initiative (RGGI) in January 2020. RGGI represents a cooperative effort to cap and reduce the power sector's CO_2 emissions. RGGI is considered the first mandatory market based program in the US to reduce greenhouse emissions, and represents a cooperative effort among the states of the Northeast to curtail emissions from the power sector. Under RGGI, CO2 emissions are capped regionally by CO_2 allowances, which can be traded between facilities. These CO_2 allowances are distributed at auction, the proceeds of which are used to invest in clean energy, energy efficiency, GHG mitigation, and consumer benefit programs. Thus, RGGI represents a market based approach to capping greenhouse gas emissions, allowing supply and demand to drive allowances, prices, and ultimately, mitigation of GHG emissions.

Each participating state (Figure 1), including Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont, has individual CO_2 Budget Trading Programs. These programs set emissions limits of CO_2 from electric power plants, issue CO_2 allowances, and establish participation in regional CO_2 allowance auctions. Although these programs work independently, they follow the RGGI Model Rule to set the limits and the allowances. These programs thus create a market-based approach where the supply and demand of these allowances and the resulting equilibrium prices are used to reduce CO_2 emissions.

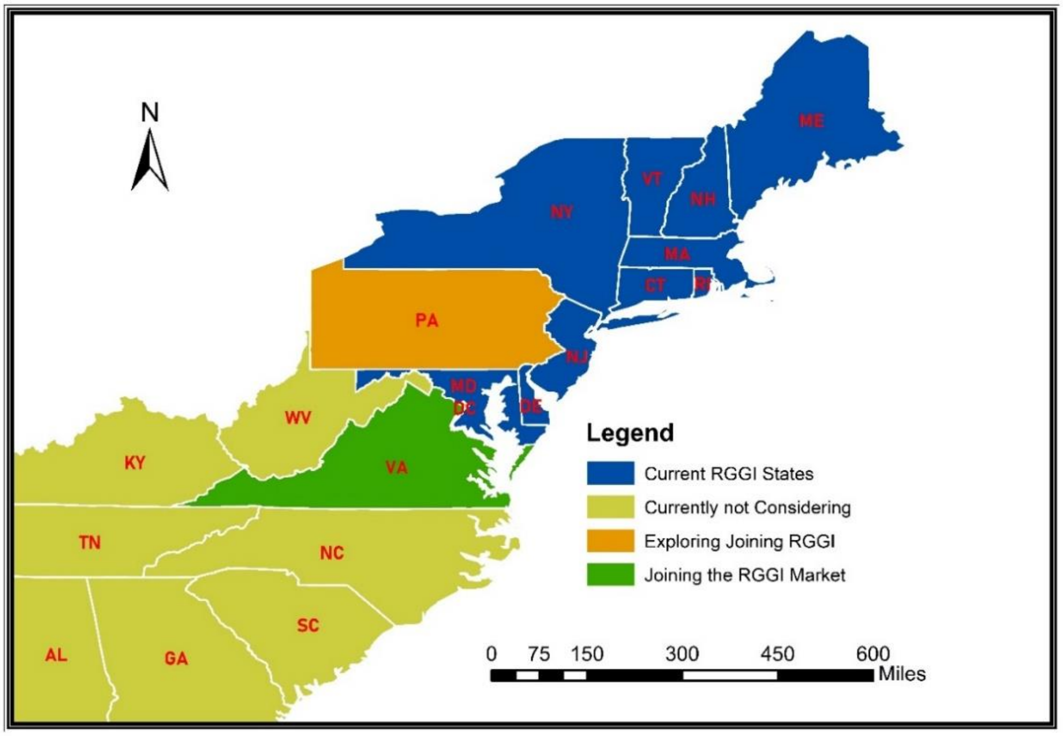


Figure 1. RGGI Member States and States in the Process of Joining the Initiative

Since its inception in 2009, RGGI has largely been a success for its member states. All states in RGGI have seen CO2 emissions drop consistently in the last 11 years, and now collectively have seen a reduction of around 40% from their 2005 numbers. These reductions have come alongside economic growth, and studies have shown that the efforts are saving both lives and money as they work to prevent significant health problems that would be caused by climate change. Thus, RGGI has been lauded for providing a workable, effective approach to curtailing GHG emissions, and has proved itself up to the task of mitigating some of the worst consequences of climate change.

For RGGI to continue its success, it must address the issue of leakage. Leakage refers to the situation that results when an action taken to reduce GHG emissions in one area causes an increase in emissions in another area where the rules that govern emissions are not as strict. In the case of RGGI, power generation systems that service member states may also provide energy to non-member states, which can erode the competitive advantage of the RGGI states. As such the leakage phenomena could undermine or even defeat RGGI's efforts, it has become critical to understand how leakage affects RGGI moving forward. Detailing how this problem works, its magnitude, and how it may grow or be reduced is imperative for developing policy to preserve the core mission of RGGI. Further, analyses can help decision makers understand how to continue adapting and growing RGGI to circumvent or conquer these problems. They can also help to find meaningful solutions, such as border adjustment or carbon pricing measures, which can leverage market mechanisms to protect RGGI member producers and discourage a ramp up of fossil fuel sources to provide energy.

The participating state's environmental regulatory agencies compare a source's covered emissions with the allowances held in determining compliance, which is evaluated at the end of each three-year control period. Interim control period compliance also exists, and requires each CO_2 budget source to hold allowances equal to 50 percent of their emissions during each interim control period. By periodically reviewing the initiative's performance and by engaging stakeholders such as state agencies, the regulated community, environmental groups, consumer and industry advocates, and other interested organizations, member states make changes to the way the initiative operates.

1.1 Carbon Allowances & Proceeds

Each state allocates its share of allowances among owners of power plants and other potentially interested parties for consumer benefits or strategic energy purposes. While the allowances are provisional in nature, they authorize the emission of a short ton of CO_2 from a regulated source.

Regulated power plants can obtain these allowances though auctions, which are regional and offered quarterly as administered by RGGI Inc., a non-profit organization set up by the states to run the program. Outside of auctions, various mechanisms, including secondary markets, exist for the distribution of allowances. The allowances that are not distributed at auctions, for instance, are distributed according to state-specific programs such as the Voluntary Renewable Energy Account, which is the most prevalent mode across the states; New Jersey (NJ) uses "fixed price contract set-aside account" and "cogeneration set-aside accounts."[1] Irrespective of where the

[1] As defined in N.J.A.C. 7:27C-1.2 Rule, "fixed price contract set-aside account" is established to make CO_2 allowances available for direct sale to a CO_2 budget source that is a certified dispatch agreement facility. The

allowance is issued, a regulated power plant can use such an allowance to demonstrate compliance in any state. Proceeds from the auctions (revenue generated from the sale of the allowances) are distributed to states, and are allocated to state general funds, education and job training programs, and the RGGI program or other GHG-reduction initiatives. Specific areas of investment include investments in energy efficiency programs, community-based or private-sector installation of renewable energy or advanced power generation systems, and credits to reduce consumers' electricity bills.

The clearing prices from auctions provide information about the market value of CO_2 allowances. The trends, despite noticeable fluctuations, are such that the firms are paying more and more for the allowances. The higher price produced by auctions means higher compliance costs as fewer allowances are being offered and sold. This has led to lower auction proceeds to RGGI states over the compliance periods. The rise in the price of allowances, despite the lower number of allowances offered over time, has led to a less than proportionate decline in revenue. Despite a degree of variability in the emission levels before 2009, the member states of RGGI nevertheless had consistently high CO_2 emissions on average. However, since the launch of the RGGI initiative, these emissions have fallen consistently over time.

1.2 Measuring Leakage Potential

Leakage is defined as an increase in emissions that occur in an external region as a result of an action taken in another region to reduce emissions. In this case, the marginal costs of generation units in RGGI states increase and generation is shifted to non-RGGI states. Specifically, RGGI caps power sector carbon emissions in participating states. The cost of purchasing emissions allowances results in an additional cost for carbon-emitting generators in RGGI states. As a result, carbon-emitting generators in NJ may reduce their generation output, thereby reducing emissions in the state. However, this situation may now become more economically attractive to comparable units in neighboring non-RGGI states which then increase their generation level, thereby negating the total emission-reduction benefits when viewed on a regional scale. In more extreme cases, the reduced generation in NJ may be replaced by more carbon-intensive resources in neighboring non-RGGI states, thereby actually increasing total regional emissions.

"cogeneration set-aside account," is established to make CO_2 allowances available to adjust the compliance obligation of a cogeneration unit.

These issues result from the fact that power systems are typically operated without respect to state borders. In some cases, an individual power market may be largely isolated within a single state, as is the case with New York, which is serviced by the single state market- New York Independent System Operator (NYISO). However, even in this case, New York can still interact with other neighboring markets through imports and exports. In other cases, multiple individual states are contained within a single power market, as is the case with Independent System Operator New England (ISO-NE) and the six New England states, and PJM, which spans NJ, Maryland, Delaware, and a host of other non-RGGI states.

Depending on the size of the leakage, the overall net effect of the capping CO_2 could undermine the environmental benefits of the initiative, power producers' investment decisions regarding generators, and the cost of energy paid by consumers. These possible unintended effects must be accurately measured and monitored, and the data then used to inform policy approaches. Understanding the magnitude of such leakage is important, for instance, in estimating the overall effectiveness of the initiative. Understanding the manner in which these emissions are occurring is also important in developing more directed policies.

2. Methodology

Emissions leakage, by definition, refers to an increase in emissions in regions not subjected to carbon regulation that results from regulations in another region. Perhaps, due to this apparent distinction of regional jurisdiction, the vast majority of literature on quantifying emissions leakage has concentrated mainly on national level policies. Only a limited number of studies are available on US sub-regional level leakage analysis (Bistline and Rose, 2018; Caron et al., 2015; Chen, 2009), most of which are focused on California and RGGI states. In general, the emissions leakage has been measured in the literature using two approaches. The first is an empirical method using historical data on energy production and related emissions that examines the pattern of leakage. Most of the studies using this empirical method, which requires historical data, pertain to the European Union Emission Trading System, which was launched in 2005. However, data over a relatively short period of time poses econometric constraints in identifying the impacts of a policy on leakage. The other approach combines theoretical and empirical data, simulating potential policy scenarios and comparing the impacts with and without a simulated policy case. This *ex-ante* approach involves using large scale models such an economy-wide CGE model or a technology rich sector specific partial equilibrium model, and measuring production outcomes, emission outcomes, or a combination of both. Table A1 in Appendix highlights some of the studies using these *ex-ante* approaches to quantify potential leakage and mitigation options.

Our study contributes to the literature mainly by integrating an electricity dispatch model with a dynamic CGE model enriched with detailed electricity generation by source. Further, we focus analysis explicitly on NJ, RGGI States, and entire Eastern Interconnect (EI) regions. In the sections below, we discuss the methodology used in this study pertaining to adopting a dispatch model and developing the CGE model, respectively.

2.1 Power System Investment and Dispatch Model

Electricity dispatch modeling strives to describe the ever-evolving balancing act between load, generation, fuel prices, and emissions goals. The scale of dispatch models can be as small as a few square miles to the size of a country, but are usually used to describe one interconnected administrative region (Wise et al., 2019). When it comes to planning the development of the power grid into the future, both peak and off-peak time must be incorporated, especially when considering variable renewable energy sources (Deetjen et al., 2016).

In this analysis we used Aurora, an electric modeling forecasting and analysis software, maintained by Energy Exemplar Pty Ltd., to estimate the potential for emissions leakage as a result of NJ joining RGGI (Energy Exemplar, 2017). An overview of the investment and dispatch model is provided in Figure 2. Aurora is a power system model that balances electricity supply and demand in hourly intervals over multi-year time horizons by simulating optimal capacity investments and retirements as well as unit-level operational decisions.

We followed a two-phase approach in the Aurora modelling: long-term expansion modelling and enhanced operational modelling.

- We applied Aurora to model power system investments, retirements, and operations throughout the EI. Our analysis considers cost and technical specifications for every generation unit in the power system with capacity greater than roughly 1 MW.
- We included new builds and retirements that were publicly announced as of early 2019, hourly demand profiles with future projections through 2030[2], regional fuel costs and

[2] We updated the hourly demand profile for PJM based on the 2020 PJM forecast: https://www.pjm.com/planning/resource-adequacy-planning/load-forecast-dev-process.aspx

projections through 2030, emission factors for each generation unit, defined by fuel type (CO_2, NO_x, SO_x, Hg), and aggregated transmission constraints between Aurora transmission zones.

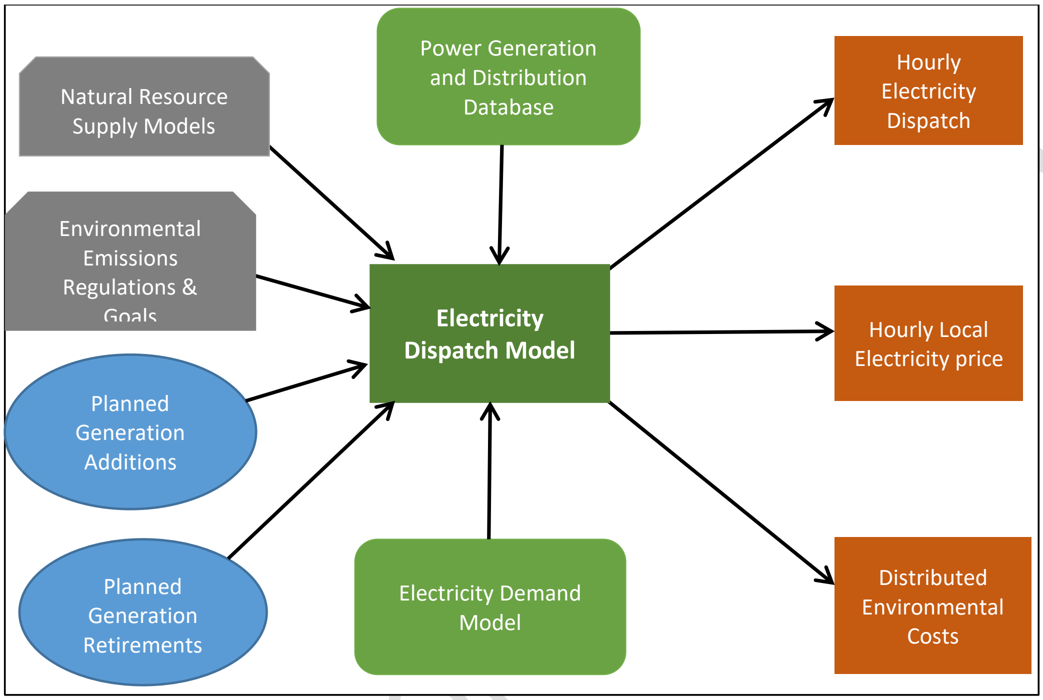


Figure 2. An Overview of the Electricity Dispatch Model

All the input data and assumptions on the above parameters were based on data provided through the Aurora platform, which is widely used in the power industry. Specifically, the analysis utilized the Aurora US-Canada 2019 v1 database and the PJM_MISO zonal system representation, which includes the entire EI but considers the PJM and MISO systems with relatively higher geographic resolution. Interactions within power systems are highly complex, and outcomes depended on a wide array of system parameters, assumptions, and projections, each of which had some level of inherent uncertainty. Therefore, modeling results should not be interpreted as concrete predictions of what will happen, but rather as a general indication of how outcomes may change as a result of a changing policy landscape or changing system conditions. We analyzed several different scenarios but do not offer any subjective judgement regarding their likelihood of occurrence. They were instead chosen to span a space of possible future outcomes and thereby provide the most insight to policy makers on how changes in certain sensitive and uncertain parameters may impact power system operations, prices, emission levels, and other key outcomes.

As such, results are typically most-effectively analyzed based on their changes relative to a reference scenario, rather than in terms of their absolute outcomes.

2.2 NJ-POWER – an Economywide CGE Model

For analyzing the overall economic impact in NJ as a result of potential leakage due to re-joining RGGI, we developed a dynamic CGE model called NJ-POWER, with explicit NJ and RGGI states in the US. The CGE framework is best suited to capture the macroeconomic effects of energy and climate policies. The models combine economic theory and empirical data to estimate policy effects while accounting for all interactions among businesses and consumers. A CGE model reveals interactions between sectors in an economy and the ripple effects from changes in one sector of the economy on all other sectors of the economy.

As discussed above, CGE models have been widely used to address carbon leakage issues, as these models appropriately capture the impact of policies on relative competitiveness of sectors and regions in an economy-wide setting. For example, Burniaux (2001) estimated leakages associated with the implementation of the Kyoto Protocol and found that leakage rates ranged from 2 to 20% compared to estimates from earlier studies. Böhringer et al. (2012) summarized the results from 12 different CGE models on the efficiency and distributional impacts of border carbon adjustment (BCA) in reducing carbon leakage. Golub (2013) used a GTAP-based dynamic CGE model (GDyn-E) to illustrate the carbon leakage resulting from Annex-I countries implementing unilateral GHG emission reductions, and decomposed this leakage into international energy prices and structural and international capital reallocation channels. Their sensitivity analysis of the leakage rate revealed that assumptions about technological flexibility and elasticity of carbon supply are important determinants of the size of leakage.

We developed the NJ-POWER model based on the GTAP-E-Power model (Peters, 2016a; Peters, 2016b). GTAP-E-Power is a comparative static model constructed based on the GTAP-E Model (Burniaux and Truong, 2002), which assumes perfect competition in all markets. As depicted in Figure 3, the model includes three agents: private household (consumer), producer firms, and government. As a standard CGE model, NJ-POWER model assumes that a representative producer firm maximizes profits in nested Constant Elasticity of Substitution functions in a perfectly competitive market for each industry/sector in each region. The firm pays income to the regional household for using the endowment commodities (land, labor, capital, and natural resources). Firms sell the final goods consequently produced by combining the endowments with the intermediates to the private households and government. In an open economy, firms also export the tradable commodities and import the intermediate inputs from other regions, but the model follows an Armington assumption accounting for product heterogeneity. The private household consumption in the model follows a non-homothetic Constant Difference of Elasticity implicit expenditure function, which allows for differences in income elasticities across commodities. Government spending is modeled by using a Cobb-Douglas sub-utility function, which maintains constant expenditure shares across all the sectors.

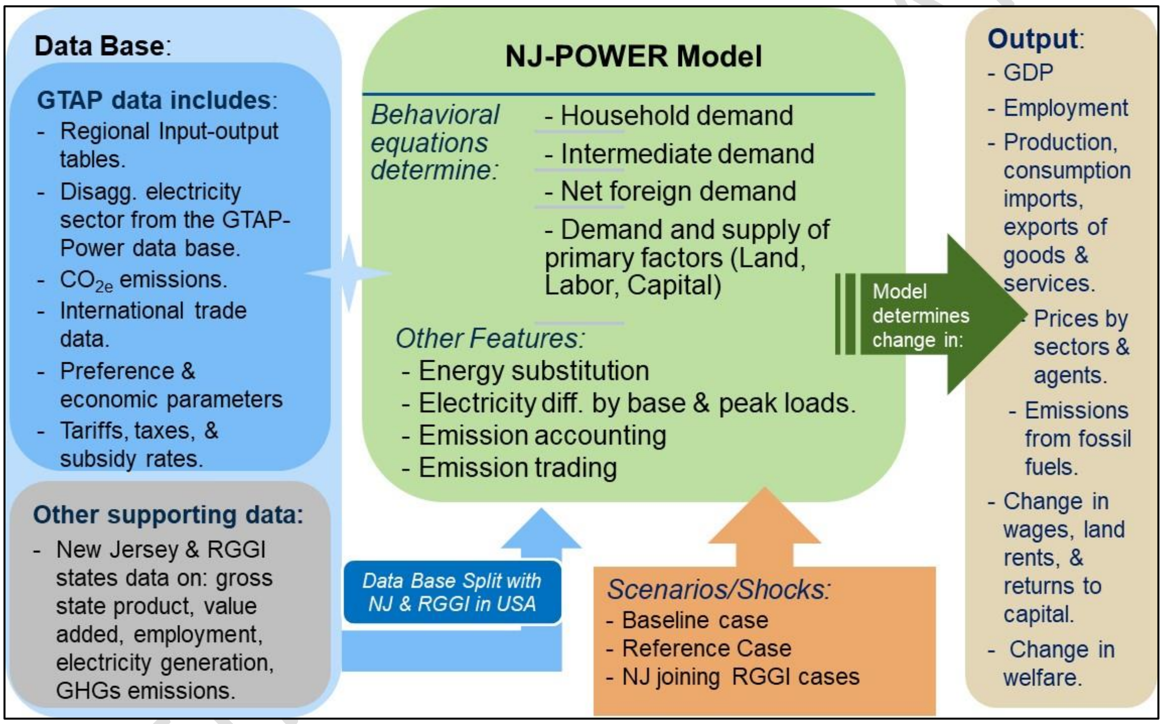


Figure 3. An Overview of the Economywide CGE Model – NJ-POWER

In addition to the standard CGE assumptions mentioned above, the GTAP-E-Power model allows for capital-energy and inter-fuel substitution, a widely used assumption to analyze energy and climate policies. The "Power" data includes the disaggregated electricity ('ely') sector, transmission, and distribution ('TnD'), as well as 11 generating technologies: nuclear, coal, gas base-load, gas peak-load, oil base-load, oil peak-load, hydro base-load, hydro peak-load, wind, solar, and 'other'. This is an ideal framework to perform electricity-detailed analyses within a CGE framework.

While the static version of GTAP-E-Power model would be useful for analyzing short run or instantaneous impact policy scenarios, a dynamic CGE offers a more appropriate onward looking framework for performing medium and long-term analyses. We built the static version of the GTAP-E-Power model into a dynamic version based on the GDyn (dynamic GTAP) model (McDougall et al., 2012) model, which is a recursive dynamic model where the agents base their decisions on adaptive expectations (meaning what will happen in the future depends on what has happened in the past). The dynamics in the GDyn model come from capital accumulation, labor productivity, and other exogenous macro variables such as GDP growth and labor supply. We first developed a static version of Power modeling and then adapted it into the dynamic version of the GDyn model and further incorporated dynamics of energy sectors such as substitutions between renewable and non-renewable energy.

2.2.1 Database in NJ-POWER Model

NJ-POWER model used the latest publicly available GTAP-v10 Database (Aguiar et al., 2019).This database is further extended to incorporate 11 different types of electricity by source of generation (Chapeliev, 2020). We used this comprehensive database and aggregated the original 76 sectors into 25 sectors[3] for computational ease and tracking (Table 1). The US is an aggregated region in the GTAP database. We further disaggregated the GTAP data base by separating NJ, RGGI states (comprising the nine states together), RoPJM regions (comprising 11 states together), and RoUSA, by splitting the US region (Table 2) (displayed in Figure 1).

Before splitting the regions, since our analyses focused on the latest developments in the energy sector in NJ and RGGI regions, we updated the macro data to 2018. For this purpose, we used historical data from secondary sources such as the US Bureau of Economic Analysis (BEA) and World Economic Outlook 2019 from International Monitory Fund, and revised the GTAP database to reflect the 2018 economy. This was accomplished through an open source software named GTAP-Adjust (Horridge, 2011), which employs an Entropy Optimization approach to target all the macro variables, while not making substantial changes in the data otherwise.

Further, we used this 2018 data base to split the US into multiple regions. For this purpose, we used secondary data on state level GDP, sectoral level, value added, production, input-output

[3] We merged the Base load and Peak load electricity types to keep consistency with the electricity types available in the Dispatch model.

tables, and employment data from the US BEA. We then utilized another open source software called "SplitReg" (Horridge, 2017), which splits the regions with realistic input-output structure.

Table 1. Aggregation of Sectors in the NJ-POWER Model

No.	Aggregated Sector Name	Comprising Original Sectors
1	Agriculture	paddy rice; wheat; cereal grains; vegetables, fruit, nuts; oil seeds; sugar cane, sugar beet; plant-based fibers; crops; bovine cattle, sheep and goats; animal products; raw milk; wool, silk-worm cocoons; fishing
2	Forestry	forestry
3	Coal	coal
4	Oil	oil
5	Gas	gas
6	Other Industries	minerals; bovine meat products; meat products; vegetable oils and fats; dairy products; processed rice; sugar; food products; beverages and tobacco products; textiles; wearing apparel; leather products; wood products; paper products, publishing; mineral products; computer, electronic and optic; manufactures
7	Petroleum	petroleum, coal products
8	Chemicals	chemical products; basic pharmaceutical products; rubber and plastic products
9	Energy Intensive Industries	ferrous metals; metals; metal products; electrical equipment; machinery and equipment
10	Automobile	motor vehicles and parts; transport equipment
11	Transmission & Distribution	electricity: transmission and distribution
12	Nuclear Electricity	nuclear base load electricity
13	Coal Electricity	coal base load electricity
14	Gas Electricity	gas base and peak load electricity
15	Oil Electricity	oil base and peak load electricity
16	Hydro Electricity	hydro base and peak load electricity
17	Wind Electricity	wind base load electricity
18	Solar Electricity	solar peak load electricity
19	Other Electricity	other base load electricity
20	Gas Distribution	gas manufacture, distribution
21	Transportation	transport; water transport; air transport; warehousing and support activities
22	Water	water
23	Construction	construction
24	Services	trade; accommodation, food and service; communication; financial services; insurance; real estate activities; business services; recreational and other service; public administration and defense; education; dwellings
25	Health care	human health and social work

Table 2. Aggregation of Regions in the NJ-POWER Model

Regions in the Model	Comprising regions
NJ	New Jersey
RGGI	Nine states together (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont)
RoPJM	11 states together (Illinois, Indiana, Kentucky, Michigan, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia, and District of Columbia)
RoUSA	All other US states not in the other groupings
RoW	Rest of world; all non-US countries

The dynamic baseline projections included macro variables such as growth in GDP, growth in population, growth in the available effective labor supply from population growth, and changes in labor productivity and capital accumulation through savings and investment for the period of 2018 through 2030. These projections are available for all the explicit regions within the US and the rest of the world in aggregate. The dynamic framework is flexible in specifying the intermediate time steps based on our analytical needs. We used yearly time steps in this analysis.

2.3 Coupling NJ-POWER with Dispatch Model

Aurora is a bottom-up power system model that simulates optimal unit-level investments, retirements and dispatch given exogenous projections of operational parameters, costs, and electricity demand among several other assumptions. The key strength of a dispatch model such as Aurora is that it provides a detailed representation of power system operations at the level of individual generation resources with hourly resolution. However, the major limitation of these bottom-up models is that they have no linkages with any other sectors of the economy (e.g. electricity demand is a fixed input parameter). The CGE models are classified as top-down models, as the economy-wide equilibrium captures inter-industry and inter-regional linkages through input-output tables and macro-economic flows. The strength of these CGE models lie in the feedback effects through economy-wide linkages; they are limited in handling greater sector-level technological details. Keeping these features in view, we exploited the strengths of both models, and coupled Aurora and NJ-POWER models to analyze the economic and environmental implications of NJ re-joining RGGI.

For estimating the electricity market-based leakage impacts under different scenarios, we applied Aurora to simulate dispatch from 2020 through 2030. As discussed in Section 2.1, the Aurora model projects future power sector emissions for individual states and throughout the entire EI. We therefore utilized Aurora to analyze the emissions leakage impacts caused when NJ joins RGGI by comparing total EI-wide emissions in the case where NJ joins RGGI to a Reference scenario wherein they do not join RGGI. This same analysis was conducted for six different parameter sensitivity scenarios, resulting in 12 total model runs. As presented in Figure 4, for each scenario, the CO_2 emissions levels determined by Aurora were fed into the NJ-POWER model as targets to obtain the economy-wide impacts of that scenario. This framework assessed direct, indirect, and distributional impacts of various policy scenarios.

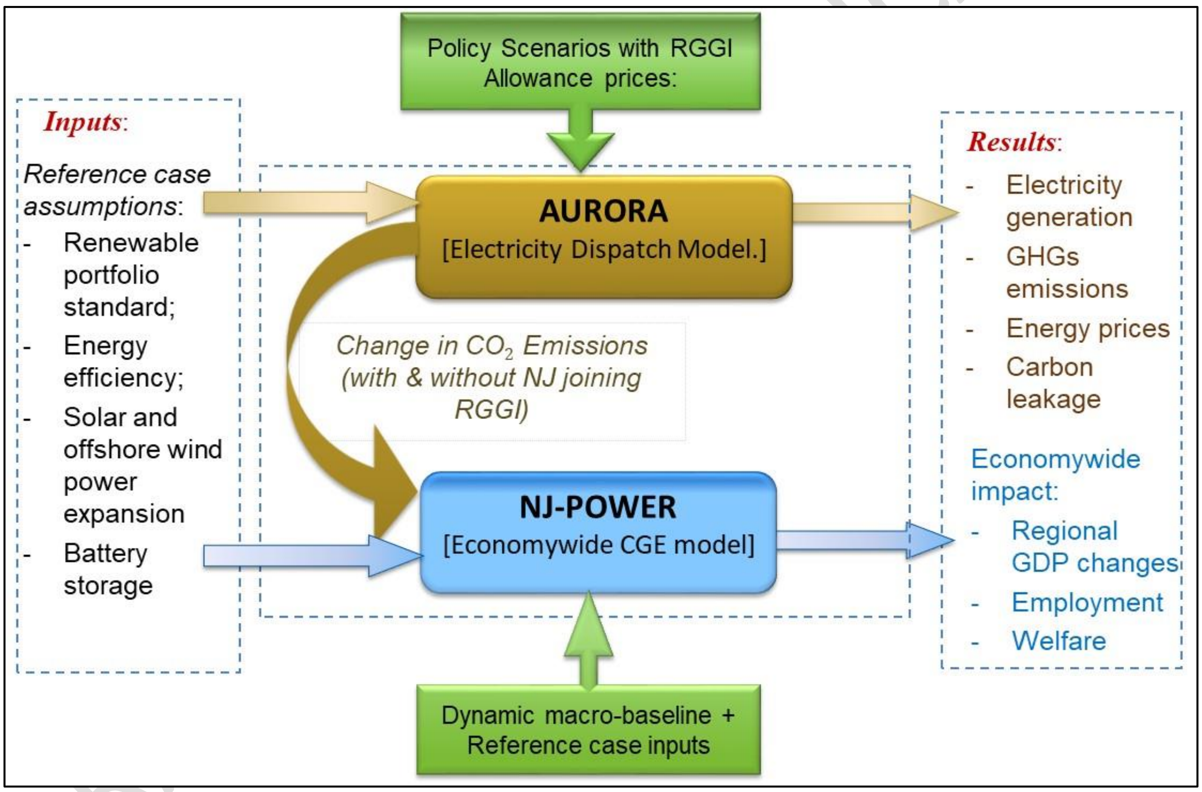


Figure 4. Coupling of Dispatch and CGE Models

The coupling framework adopted in this study helped in analyzing the interactions between macro-economic, energy, and environmental systems linked together through a closed loop. The coupling of the two models provided a consistent analytical framework to evaluate the impacts of GHG emissions related policies on the economy and help finding better mitigation options. The NJ-POWER model is capable of endogenously computing the change in CO2 emissions due to change in electricity and other energy sectors. However, we exogenously imposed the CO2 changes from the dispatch model for each scenario so that economy-wide impacts due to the electricity sector alone could be distinctly analyzed.

2.4 Designing Policy Scenarios

In this paper, analyzed the emissions leakage impacts of six different parameter sensitivity scenarios. For each scenario, we modeled power system operations from 2020 through 2030 for a Reference scenario where NJ does not join RGGI and a policy sensitivity scenario where it does. This resulted in 12 total model simulations for this eleven-year period. The Aurora model directly monitored and quantified emissions of CO_2, NO_x, SO_x, and Hg at the state-level and throughout the entire EI. The total potential leakage impact was determined based on the geographic emissions profiles that resulted from each of the considered scenarios. We defined emissions leakage realized under each scenario as the difference in emissions levels between these two policy cases across the entire EI. Within each sensitivity scenario, we assumed that NJ's decision to join RGGI does not impact investment or retirement decisions in other states. This assumption significantly reduces computational time and was motivated by preliminary analysis which indicated that external investments would be largely unaffected by this decision. The six considered parameter sensitivity scenarios are outlined in Table 3, and additional quantitative detail is provided in Table 4.

Table 3. Description of Scenarios Analyzed

Scenario	Description
Mid CO_2 Price (Reference)	RGGI allowance prices are based on the midpoint between the emissions containment reserve (ECR) trigger price and the cost containment reserve (CCR) trigger price
Low CO_2 Price	RGGI allowance prices are based on the ECR trigger price
High CO_2 Price	RGGI allowance prices are based on the CCR trigger price
High NG Price	Henry Hub NG price projections are based on the US Energy Information Administration (EIA) Low Oil and Gas Supply case from the 2020 Annual Energy Outlook
High PJM Load	Both average and peak electricity demand throughout PJM are escalated relative to the Reference scenario by .30% per year starting in 2021, up to 3.0% in 2030
Low NJ NG Price	NG fuel prices in NJ are reduced by 10% for all generation units

All the scenarios above were analyzed through a cost-based approach to modelling RGGI compliance – three allowance cost scenarios were included based on RGGI 2017 rules, and the thermal units with capacity greater than 25 MW in RGGI states were subjected to RGGI allowance prices. Unless otherwise specified, input assumptions that applied to the Reference scenario apply to the other scenarios as well.

Table 4. Parameter Assumptions under Different Scenarios

Scenario	NJ Joins RGGI?	Allowance Price (nominal$/ton) (2020/2030)	Henry Hub NG Price (2019$/MMBtu) (2020/2030)	PJM Peak Load (MW) (2020/2030)	NJ NG Price Reduction
Mid CO_2 Price (Reference)	No	$5.70 / $17.46	$2.95 / $3.57	154,047 / 163,527	0%
Mid CO_2 Price - NJ in RGGI	**Yes**	$5.70 / $17.46	$2.95 / $3.57	154,047 / 163,527	0%
Low CO_2 Price	No	$5.70 / **$11.02**	$2.95 / $3.57	154,047 / 163,527	0%
Low CO_2 Price - NJ in RGGI	**Yes**	$5.70 / **$11.02**	$2.95 / $3.57	154,047 / 163,527	0%
High CO_2 Price	No	$5.70 / **$23.89**	$2.95 / $3.57	154,047 / 163,527	0%
High CO_2 Price- NJ in RGGI	**Yes**	$5.70 / **$23.89**	$2.95 / $3.57	154,047 / 163,527	0%
High NG Price	No	$5.70 / $17.46	**$3.12 / $4.78**	154,047 / 163,527	0%
High NG Price - NJ in RGGI	**Yes**	$5.70 / $17.46	**$3.12 / $4.78**	154,047 / 163,527	0%
High PJM Load	No	$5.70 / $17.46	$2.95 / $3.57	154,047 / **168,245**	0%
High PJM Load - NJ in RGGI	**Yes**	$5.70 / $17.46	$2.95 / $3.57	154,047 / **168,245**	0%
Low NJ NG Price	No	$5.70 / $17.46	$2.95 / $3.57	154,047 / 163,527	**10%**
Low NJ NG Price – NJ in RGGI	**Yes**	$5.70 / $17.46	$2.95 / $3.57	154,047 / 163,527	**10%**

Note: The **Bold** text indicates a parameter that is changed relative to Reference scenario. Other parameters are held constant across all scenarios.

2.4.1 Reference Scenario

A number of Reference scenario assumptions for different parameters over the period of 2020 through 2030 are provided in Table 5. These assumptions include: (a) NJ meeting its existing energy policy goals such as RPS of 50% by 2030 and imported Renewable Energy Certificates (RPS mandates for other states in the EI are also considered in the Reference scenario); (b) achieving energy efficiency in terms of reduction in electricity consumption by up to 2% each year; (c) increased efficiency in NG consumption by around -0.75% per year (included only the NJ-POWER model); (d) addition of solar photovoltaic capacity of 400 MW per year (4400 MW by 2030); (e) addition of storage capacity of 2 gigawatts by 2030; and (d) increase in offshore wind capacity of 3.5 gigawatts by 2030 as per NJ Governor's executive order.

Table 5. Reference Scenario Assumptions

Year	Renewable Portfolio Standard (RPS)	Energy Efficiency in Electricity consumption*	Energy Efficiency in NG consumption**	Solar photovoltaic (BTM solar, 400+ MW/year)	New Battery Storage (MW)	New Offshore Wind (MW)
2020	21.00%	0.00%	-0.25%	400		
2021	22.50%	-0.43%	-0.50%	400	600	
2022		-0.90%	-0.50%	400		
2023		-1.29%	-0.50%	400		
2024		-1.72%	-0.75%	400		1100
2025	30.00%	-2.15%	-0.75%	400		
2026		-2.15%	-0.75%	400		
2027		-2.15%	-0.75%	400		1200
2028		-2.15%	-0.75%	400		
2029		-2.15%	-0.75%	400		1200
2030	50.00%	-2.15%	-0.75%	400	1400	
2031	51.50%	-2.15%	-0.75%			1200
2032	53.00%	-2.15%	-0.75%			
2033	54.50%	-2.15%	-0.75%			1400
2034	56.00%	-2.15%	-0.75%			
2035	57.50%					1400

Note: * Relative to PJM 2020 forecast, assumes PJM already includes -0.75% EE in its forecast
** NG consumption efficiency was included only in the NJ-POWER model.

The model was also able to select generation resources to add or retire on the basis of economics. However, under the modeling scenarios examined, the mandated investments in NJ along with economic investments in other states were sufficient to serve projected demand growth in the region. In addition to these assumptions, the Reference scenario was based on 2020 PJM demand projections and RGGI CO_2 allowance prices, which are mid-point prices between CCR and ECR triggers (Figure 5). The mid-point allowance price ranged from \$5.70/ton of CO_2 in 2020 to \$17.46/ton in 2030 in nominal dollars (\$5.56/ton and \$13.30/ton in constant 2019 dollars). In addition to this mid-point price-based Reference scenario, we analyzed two allowance price sensitivity scenarios as discussed below. Notably, allowance prices have historically been lower than the mid-point values that serve as input assumptions for the Reference scenario, as is evident in Figure 5. Therefore, the Reference scenario modeling results should not be interpreted as a subjective prediction of what will occur or even the most likely future outcome. Rather, by comparing reference results against the sensitivity scenarios with higher and lower allowance prices, policy makers can broadly understand the potential leakage impacts associated with allowance price variations. Hereafter, all financial results have been presented in constant 2019 dollars based on an assumed 2.5% annual rate of inflation. Note also that all references to emissions throughout the following sections refer only to those emissions generated by the power sector. Emissions from other sources such those directly caused by non-electric transportation and non-electric industrial activity are not subject to RGGI allowance prices and fall outside the scope of this analysis.

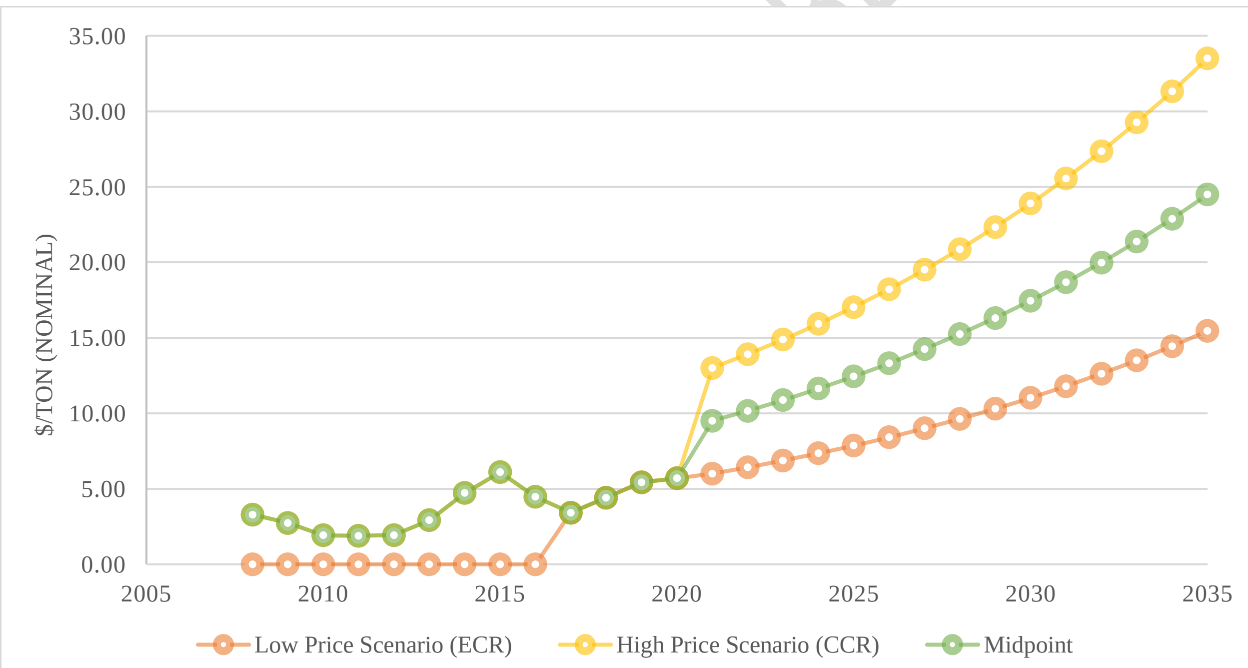


Figure 5. Historical and Modelled Future RGGI CO_2 Allowance Prices ($/mt)

2.4.2 High RGGI Allowance (CCR) Price Scenario

The cost containment reserve (CCR) provides flexibility and cost containment for the program. That means the CCR price is intended to keep the allowance prices from rising above the trigger price. The CCR consists of additional units of CO2 allowances compared to annual

CO2 budget under the RGGI program; these would be made available for purchase when the demand for allowances leads clearing price to exceed the trigger price. In this scenario, all the assumptions of the Reference scenario hold true except that instead of mid-point allowance price, we included high allowance price (CCR price). As seen from Figure 5, the CCR price was set to $10.00/ton in 2017 and escalated by 2.5% annually through 2020. It will be then be set to $13.00/ton in 2021 and escalated by 7% annually through 2035.

2.4.3 Low RGGI Allowance (ECR) Price Scenario

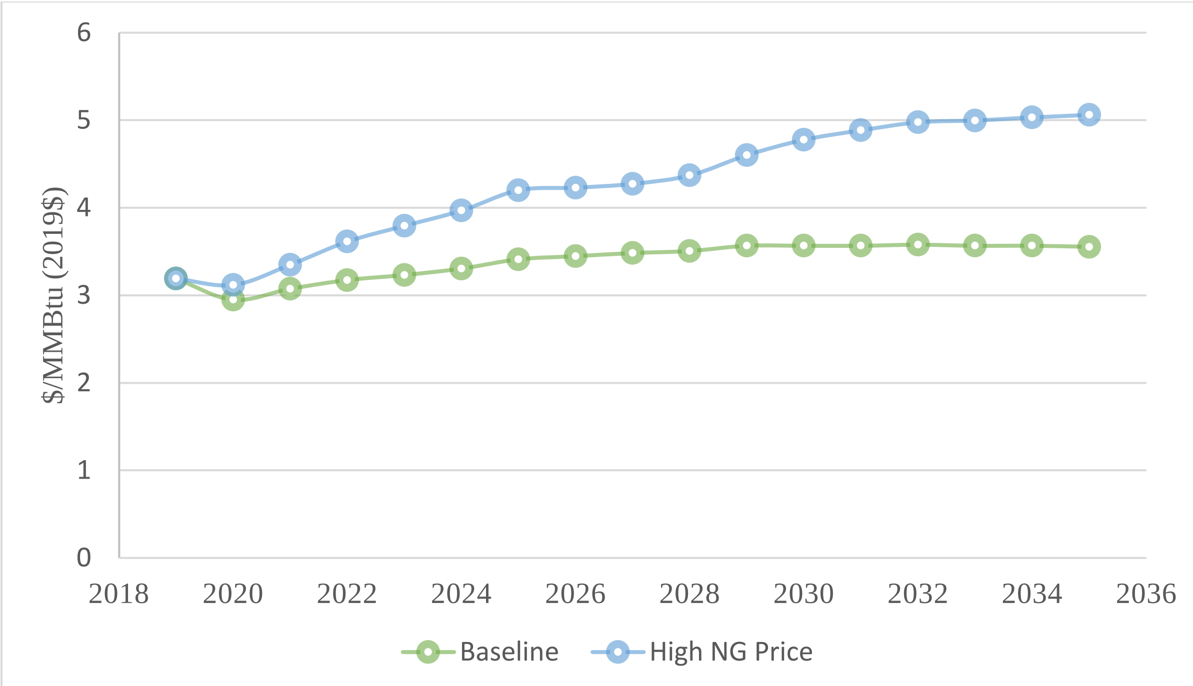
In the beginning of 2021, RGGI is planning to introduce an ECR which withholds allowances from circulation if prices fall below established trigger prices. The ECR triggers only if emission reduction costs are lower than the projected prices. As depicted in Figure 3.6, the ECR price is assumed to start at $6.00/ton of CO_2 in 2021, with 7% annual escalation through 2035. In this scenario, we included all the assumptions of the Reference scenario while using the ECR price in lieu of mid-point allowance price.

In addition to these two allowance price sensitivity scenarios, we designed four additional scenarios on sensitivity with respect to different parameters, as described below.

2.4.4 High and Low NG Price Scenarios

As reported by the US Energy Information Administration (EIA, 2020), nearly 44% of electric power consumed in NJ came from NG-based generation in 2018. The International Energy Agency (IEA, 2020) forecasts that nearly 70% of the growth in gas production in the coming decade is expected to come from US due to its shale industry, which has been largely responsible for a dramatic reduction in the cost of NG for power generation in the US over the past decade. However, the market forces on demand and supply due to changing economic conditions have made the shale industry vulnerable in particular. Since NG is the primary heating oil as well, volatility in gas prices could directly translate into volatility in electric prices impacting the wholesale power market. For this reason, we performed high and low NG price scenarios.

In the High NG Price scenario, we retained most of the Reference scenario assumptions, including mid-point RGGI allowance prices, but used NG fuel prices that are based on Henry Hub projections from the US EIA 2020 Annual Energy Outlook “low oil and gas supply” scenario (as shown in Figure 6).



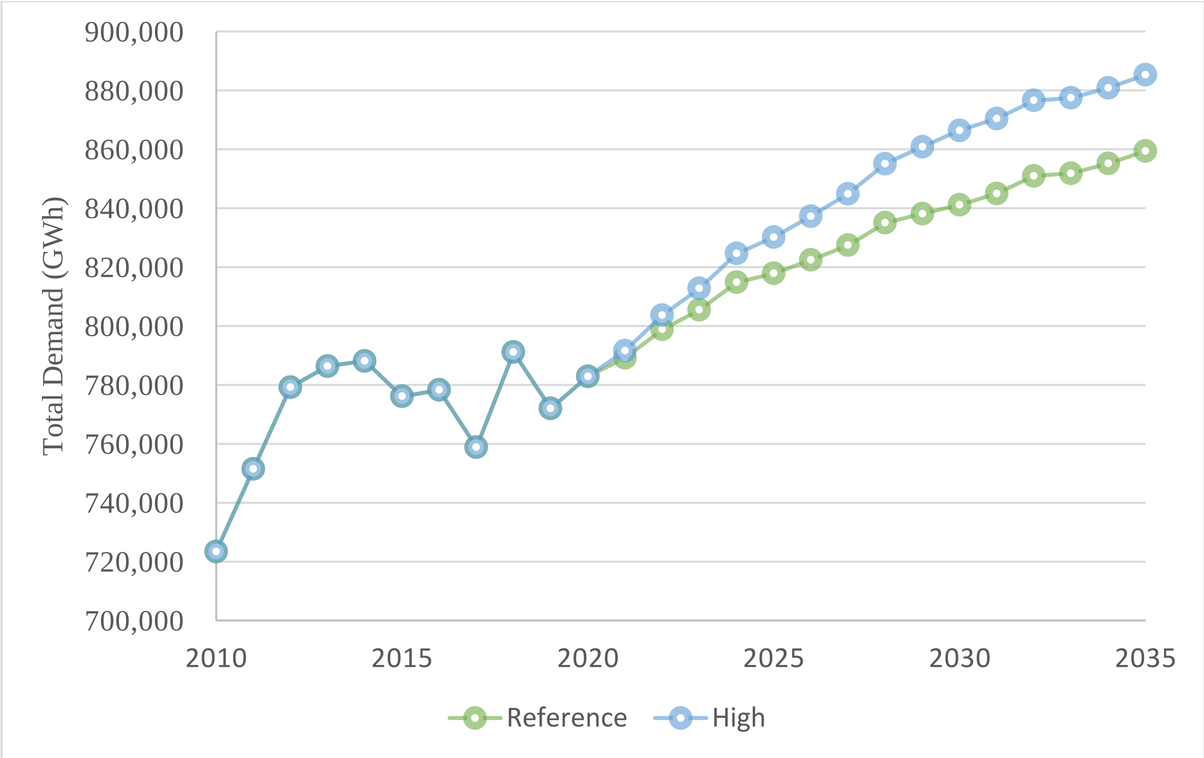
Source: EIA, 2020

Figure 6. Henry Hub NG Prices ($/MMBtu)

These adjusted NG prices were applied throughout the entire EI. The Aurora model further augmented these price projections based on its complex internal NG pricing framework to generate monthly NG prices for different regions and units. In the Low NJ NG Price scenario, all the Reference scenario variables including mid-point RGGI allowance price were kept constant, while the NG prices only in NJ were reduced by 10%. This sensitivity scenario explored the impact of NG generation units becoming more economically attractive relative to those in neighboring states such as Pennsylvania.

2.4.5 High PJM Demand Scenario

PJM provides a long-term demand forecast estimated based on historical data, simulated with weather data (Figure 7). As mentioned above, the Reference scenario included +2.15% energy efficiency in NJ on top of the PJM projections. In the High PJM Demand scenario, we assumed an increase in both average and peak demand of +3.0% relative to PJM's forecasted demand. This relative increase ramps up linearly starting in 2021 (e.g. demand is 0.3% higher than Reference in 2021, 1.5% higher in 2025 and 3.0% higher in 2030).



Source: [PJM 2020 Load Forecast]

Figure 7 PJM Demand Forecast (GWh)

3. Results

The primary effect of New Jersey joining RGGI identified by the model, with respect to energy generation mix, is a decrease in natural gas generation from units located in the state. By 2030, the relative change in cost of production results in New Jersey reducing its NG generation by 20,312 gigawatt-hours (GWh). Coal generation in the state also decreases as a result of its joining RGGI, although coal represents a much smaller part of New Jersey's energy mix, so the aggregate change is small compared to the impact on Natural Gas. Most of this decrease in New Jersey's generation is picked up by out of state energy generating units, which are primarily natural gas based. The model predicted only a small increase coal generation in non-RGGI states such as in Pennsylvania (2.1%) and West Virginia (1.7%). The overall net reduction in generation within New Jersey is met by net higher generation in a number of nearby states in 2030, most notably Pennsylvania, Maryland, New York, and Delaware. The cost of RGGI allowances changes the cost of energy production in New Jersey to the degree that coal-using units in Delaware, Maryland, Pennsylvania and West Virginia become more competitive.

Participation in RGGI results in New Jersey based power producers reducing their CO_2 emissions by 45% (8.7 million tons [mt]) between 2020 and 2030. However, the model results also show that emissions from units located outside of New Jersey will increase by 11.6 mt, more than offsetting the reductions realized within New Jersey. Thus, the net effect of New Jersey joining RGGI is fewer CO_2 emissions from NJ, but more CO_2 emissions when the Eastern Interconnect is considered as a whole. The results show that the effect of NJ joining RGGI will shift the energy production mix in the relevant states to a point where there is a net increase in CO_2 emissions. These results show that leakage is greater than the Reference scenario when the allowance price is higher, and is lower when the allowance price is lower.

New Jersey, with 2.71% of the US population, contributes 3.06% of the US GDP. With the implementation of the Reference scenario that incorporates significant changes in electricity generation mix (particularly on renewables), and when NJ joined RGGI, the expansion of these renewable sectors is clearly visible, particularly after 2024. The real GSP in NJ changes considerably only after 2024, primarily because the capacity of clean electricity such as solar and offshore wind rapidly expand at this time, enabling the New Jersey economy to supply cleaner electricity domestically. Cumulatively, the model predicted an increase in GSP across all the scenarios when New Jersey joined RGGI.

Impact on GSP across the six scenarios when NJ joined RGGI showed a marginal increase in real GSP by around 0.65% in the Reference scenario. The GSP change was found be the highest in the High CO_2 Price scenario (0.82%) and lowest in the Low CO_2 Price scenario (0.56%). These results offer insights on how the RGGI proceeds that are invested back into the NJ economy can contribute to the overall growth of electric vehicle infrastructure, energy efficiency, energy assistance, and conservation and forestry programs. The GSP multiplier computed with respect to investment in RGGI proceeds indicates gains in GSP with respect to a dollar investment from the proceeds. The Low CO_2 Price scenario showed greater GSP gain relative to other scenarios, such as the High NJ NG price and High PJM Demand scenarios.

The model predicted cumulative change in employment across sectors in the Reference scenario. The sectors that gained the highest number of jobs in 2030 were wind power generation (the sector includes primarily offshore wind) (2,850), followed by solar power (2,427), transportation (1,571), construction (874), and services (331). The latter two sectors are the indirect related to the electricity generation sectors, which gain from RGGI initiative. Overall job loss across other sectors of the economy is relatively small. As implied from these results, New Jersey reduces CO_2 emissions significantly and boosts its renewable electricity portfolio considerably in the coming decade, thereby positively contributing to the growth of the greener economy.

--- RESULTS SECTION WILL BE ADDED SOON ----

References

Aguiar, A., Chepeliev, M., Corong, E., McDougall, R., and van der Mensbrugghe, D. (2019). The GTAP Data Base: Version 10. *Journal of Global Economic Analysis*, 4(1), 1-27. Retrieved from: https://www.jgea.org/resources/jgea/ojs/index.php/jgea/article/view/77

Bistline, J. E. T., Merrick, J., and Niemeyer, V. (2020). “Estimating Power Sector Leakage Risks and Provincial Impacts of Canadian Carbon Pricing”. *Environmental and Resource Economics*, *76*(1), 91–118.

Böhringer, C., Balistreri, E. J., and Rutherford, T. F. (2012). “The role of border carbon adjustment in unilateral climate policy: Overview of an Energy Modeling Forum study (EMF 29)”. *Energy Economics*, *34* (2), S97–S110.

Böhringer, C., Rosendahl, K. E., and Storrøsten, H. B. (2017). Robust policies to mitigate carbon leakage. *Journal of Public Economics*, *149*, 35-46.

Brown, M. A., Kim, G., Smith, A. M., and Southworth, K. (2017). Exploring the impact of energy efficiency as a carbon mitigation strategy in the U.S. *Energy Policy*, *109*(October), 249–259.

Brown, D. P., Eckert, A., and Eckert, H. (2018). “Carbon pricing with an output subsidy under imperfect competition: The case of Alberta’s restructured electricity market”. *Resource and Energy Economics*, *52*, 102–123.

Brown, M. A., and Li, Y. (2019). “Carbon pricing and energy efficiency: pathways to deep decarbonization of the US electric sector”. *Energy Efficiency*, *12*, 463–481.

Burniaux, J. (2001). “International Trade and Investment Leakage Associated with Climate Change Mitigation”. Presented at the 4th Annual Conference on Global Economic Analysis, Purdue University, USA.

Burniaux, J., and Truong, T. (2002). "GTAP-E: An Energy-Environmental Version of the GTAP Model", GTAP Technical Paper No. 16, Center for Global Trade Analysis. Purdue University, West Lafayette, IN.

Caron, J., Rausch, S., and Winchester, N. (2015). Leakage from sub-national climate policy: The case of California’s cap-and-trade program. *The Energy Journal*, *36*(2), 167–190.

Chepeliev, M. (2020). “GTAP-Power 10a Database: a Technical Note.” Research Memorandum No. 31, Center for Global Trade Analysis, Purdue University, West Lafayette, IN.

Elliott, J., Foster, I., Kortum, S., Munson, T., Perez-Cervantes, F., and Weisbach, D. (2010). “Trade and Carbon Taxes,” *American Economic Review: Papers and Proceedings*, 100(2), 465–69.

Energy Information Agency (EIA) (2020). “New Jersey – End-use Energy Consumption 2018, estimates.” U.S. Energy Information Administration (EIA), Department of Energy, United States. Retrieved from: https://www.eia.gov/beta/states/states/nj/overview

Energy Exemplar. (2017). Auroraxmp. Available at: https://energyexemplar.com/products/aurora-electric-modeling-forecasting-software/.

Golub, A. (2013). "Analysis of Climate Policies with GDyn-E.", GTAP Technical Paper No. 32, Center for Global Trade Analysis. Purdue University, West Lafayette, IN.

Horridge, M. (2011). "GTAPAdjust – A Program to balance or adjust GTAP Data Base." Center of Policy Studies, Victoria University, Melbourne, Australia. Item TPMH0104, retrieved from http://www.copsmodels.com/archivep.htm

Horridge, M. (2017). "SplitReg – A Program to Create a New Region in a GTAP Data Base." Center of Policy Studies, Victoria University, Melbourne, Australia. Item TPMH0105, retrieved from http://www.copsmodels.com/archivep.htm

International Energy Agency (IEA) (2020). "Gas 2020 – Analyzing the Impact of the Covid-19 pandemic on Global Natural Gas Markets." International Energy Agency (IEA). Retrieved from: https://www.iea.org/reports/gas-2020/2021-2025-rebound-and-beyond

McDougall, R., T. Walmsley, A. Golub, E. Ianchovichina, and K. Itakura. (2012). "An Overview of the Dynamic GTAP Data Base: The Data Base Construction and Aggregation Programs", in *Dynamic Modeling and Applications for Global Economic Analysis*, edited by Ianchovichina and Walmsley, Cambridge University Press.

New Jersey Board of Public Utilities. (2019). "2019 Energy Master Plan: Pathway to 2050." Trenton, New Jersey. Retrieved from: https://nj.gov/emp/docs/pdf/2020_NJBPU_EMP.pdf

Peters, J.C. (2016a). "The GTAP-Power Data Base: Disaggregating the Electricity Sector in the GTAP Data Base." *Journal of Global Economic Analysis, 1*(1), 209-250.

Peters, J.C. (2016b). "GTAP-E-Power: An Electricity-detailed Economy-wide Model." *Journal of Global Economic Analysis, 1*(2), 156-187.

PJM. (2020). "Initial PJM Carbon Pricing Study Results Presented." Retrieved from PJM website: https://insidelines.pjm.com/initial-pjm-carbon-pricing-study-results-presented/

Regional Greenhouse Gas Initiative (RGGI). (2020a). "Elements of RGGI." Retrieved from RGGI website: https://www.rggi.org/program-overview-and-design/elements

Regional Greenhouse Gas Initiative (RGGI) (2020b). "*The Investment of RGGI Proceeds in 2018*." Retrieved from: https://www.rggi.org/sites/default/files/Uploads/Proceeds/RGGI_Proceeds_Report_2018.pdf

New Jersey (2020) "RGGI Strategic Funding Plan – years 2020 through 2022." The New Jersey Department of Environmental Protection (NJDEP), the New Jersey Economic Development Authority (NJEDA), and the New Jersey Board of Public Utilities (NJBPU). Retrieved from: https://nj.gov/rggi/docs/rggi-strategic-funding-plan.pdf

Yang, W., Pan, Y., Ma, J., Yang, T., and Ke, X. (2020). "Effects of allowance allocation rules on green technology investment and product pricing under the cap-and-trade mechanism." *Energy Policy*, *139*.

Winchester, N., and Rausch, S. (2013). A numerical investigation of the potential for negative emissions leakage. *American Economic Review*, *103*(3), 320-325. https://pubs.aeaweb.org/doi/pdfplus/10.1257/aer.103.3.320

Wise, M., Patel, P., Khan,Z., Kim, S., Hejazi, M. and Iyer, G. (2019) "Representing power sector detail and flexibility in a multi-sector model." Energy Strategy Reviews. 26.

Zakaria, R. (2019). MJBandA Electric Sector Modeling – Summary of Results. *PJM*. Available at https://www.pjm.com/-/media/committees-groups/task-forces/cpstf/20191024/20191024-item-06-carbon-pricing-modeling.ashx.

Appendix

Table A1. Modeling Approaches Used in Carbon Leakage Studies

Model Type	Study	Approach	Key Findings
Dispatch (FACETS)	Zakaria (2019)	Framework for Analysis of Climate Energy-Technology Systems (FACETS) model uses an energy system to incorporate local to federal policies with several parameters—including leakage mitigation—to find cost-effective energy configuration.	Under RGGI policies, leakage mitigation tends to increase the carbon allowance prices.
Dispatch + CGE **(NA-REGEN)**	Bistline et al. (2020)	Electric sector investments and spatial and temporal details of operations are input to an integrated dispatch/CGE mode (North American Regional Economy, Greenhouse Gas, and Energy – NA-REGEN)l to estimate leakage risk.	Leakage in Canada differs based on assumptions (NG prices, etc.) and can range from 13% (high gas price scenario, US border cost adjustment (BCA) to 76% (lower gas price scenario, no leakage mitigation measures).
Dispatch (Auroraxmp)	Carley (2011)	A dynamic, long-term electricity dispatch model is used to explore impacts of decarbonization in comparative policy scenarios.	Regional efforts have more long-term decarbonization success than states operating independently because of the issues of carbon leakage. A carbon price of \$50/metric ton of CO_2 can generate substantial carbon savings.
CGE (USREP)	Winchester and Rausch (2013)	Prospects of leakage are evaluated in multi-region CGE model (US Regional Energy Policy – USREP) for alternative fossil fuel supply elasticity values.	American interregional mobility of capital and labor does not greatly affect leakage.
CGE (CIM-EARTH)	Elliott et al. (2010)	Various global scenarios for taxing emissions are assessed in a CGE model called Community Integrated Model of Economic & Resource Trajectories (CIM-EARTH).	Leakage ranges from 15 to 25% depending on the tax rate.

CGE	Böhringer et al. (2017)	A numerical model (including 2 regions and 4 production sectors) is used with a CGE to simulate different policy scenarios.	A combination of rebating and a consumption tax for emission-intensive and trade-based goods can produce the same effects as border carbon adjustment.
CGE	Schinko et al. (2014)	A multi-regional CGE is used to assess impact of switching carbon-free technology over border carbon adjustment.	When looking at the iron and steel industries, a carbon-free technology switch in iron production considerably reduces total leakage.
CGE	Caron et al. (2015)	A calibrated, multi-regional CGE quantifies potential leakage in California under various electric importation scenarios.	Unrestricted imported electricity in California's cap-and-trade program increases out-of-state emissions by 45% of the domestic reduction. If imported electricity is included and "resource shuffling" is banned, overall leakage is 9%.
Partial Equilibrium	Fowlie (2009)	Emissions leakage under incomplete regulation and imperfect competitive scenarios are investigated for California using a model to simulate the state's electricity sector in a source-based cap and trade program.	In a partial equilibrium setting (a market-based scenario of CO_2 emissions regulation in California) regulation that exempts out-of-state electricity producers achieves about 1/3 of total emissions reductions under complete regulation at more than 2x the cost per ton.